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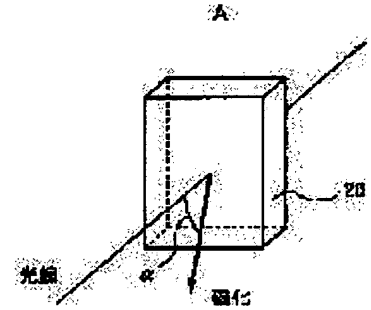
(54) FARADAY ROTATOR

(57)Abstract:
PROBLEM TO BE SOLVED: To provide an optical device using a Faraday rotator having satisfactory temperature characteristics in the style of use so that the temperature dependency of a Faraday rotating angle in the Faraday rotator is reduced and especially a magnetizing direction is changed.
SOLUTION: Concerning this Faraday rotator, the plane of polarization of polarized light transmitting a Faraday element 20 is rotated by impressing an external magnetic field to the Faraday element. When an angle formed by the magnetizing direction of the Faraday element and the direction of a light beam is defined as α, the temperature change amount of a Faraday rotating angle is reduced by impressing the external magnetic field in the direction in which the change amount of the Faraday rotating angle based on temperature dependency at the angle α and the change amount of the Faraday rotating angle based on the temperature dependency of a Faraday effect can become mutually different codes and one absolute value can be less than the double of the other absolute value. The best configuration is to impress the external magnetic field in the direction in which the codes are mutually different and the absolute values are almost equal.

A



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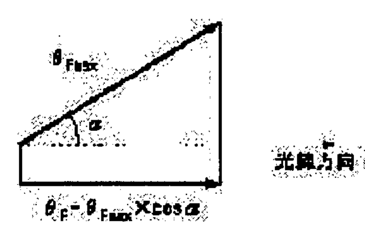

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CLAIMS

[Claim(s)]
[Claim 1] In the Faraday-rotation child who rotates the plane of polarization of the polarization which penetrates a Faraday cell by impressing an external magnetic field to a Faraday cell The variation of the Faraday-rotation angle by the temperature dependence of an angle alpha when the angle of the magnetization direction of a Faraday cell and the direction of a beam of light to make is set to alpha, The Faraday-rotation child to whom the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect impressed the external magnetic field in the direction in which it is a different sign mutually, and one absolute value becomes under the double precision of the absolute value of another side, and made small the amount of temperature changes of a Faraday-rotation angle.
[Claim 2] By impressing an external magnetic field to the Faraday cell which consists of a single or multiple magneto optics crystal In the Faraday-rotation child who rotates the plane of polarization of the polarization which penetrates a Faraday cell The variation of the Faraday-rotation angle by the temperature dependence of an angle alpha when the angle of the magnetization direction of a magneto optics crystal and the direction of a beam of light to make is set to alpha, The Faraday-rotation child to whom the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect impressed the external magnetic field to the single direction in which it is a different sign mutually, and one absolute value becomes under the double precision of the absolute value of another side, and made small the amount of temperature changes of a Faraday-rotation angle.
[Claim 3] The Faraday-rotation child according to claim 1 or 2 who the variation of the Faraday-rotation angle by the temperature dependence of an angle alpha and the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect are different signs mutually, and impresses an external magnetic field in the direction where an absolute value is almost equal.
[Claim 4] By impressing an external magnetic field to the Faraday cell which consists of two or more magneto optics crystals In the Faraday-rotation child who rotates the plane of polarization of the polarization which penetrates a Faraday cell The variation of an angle alpha 1, alpha 2, and the Faraday-rotation angle by the temperature dependence of ... when the direction of a magneto optics crystal is changed and arranged and the angle of the magnetization direction of each magneto optics crystal and the beam-of-light transparency direction to make is made into alpha 1, alpha 2, and ..., Total with the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect The Faraday-rotation child who impressed the external magnetic field in the direction which becomes in an absolute value below total of the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect of each magneto optics crystal, and made small the amount of temperature changes of a Faraday-rotation angle.
[Claim 5] The Faraday-rotation child according to claim 1 to 4 whose magneto optics crystal is 3 (RBi) 5 (FeM) O12 or (RBi) 3 Fe 5O12 (however, one or more sorts of elements chosen from the rare earth elements in which R contains an yttrium, one or more sorts of elements which M can replace by iron) produced by the liquid-phase-epitaxial method.

[Claim 6] The Faraday-rotation child according to claim 1 to 4 whose magneto optics crystal is Y3 Fe 5O12.
[Claim 7] In the Faraday-rotation child who rotates the plane of polarization of the polarization which penetrates a Faraday cell by impressing an external magnetic field to a Faraday cell Composition of the magneto optics crystal which is a Faraday cell is Tb1.00Y0.65Bi1.35Fe4.05Ga 0.95O12, and the magneto optics crystal is received. The Faraday-rotation child who impressed the magnetic field on the line which connected the position of 24 degrees to the field from the field (-1-12) on (111) and the maximum periphery circle of the center of a stereographic projection view (-101), and made small the amount of temperature changes of a Faraday-rotation angle.
[Claim 8] In the Faraday-rotation child who rotates the plane of polarization of the polarization which penetrates a Faraday cell by impressing an external magnetic field to a Faraday cell Composition is Tb1.00Y0.65Bi1.35Fe4.05Ga 0.95O12, and considers as a Faraday cell using three magneto optics crystals of the same thickness mostly. As opposed

to two of magneto optics crystals of they Impress a magnetic field on the line which connected the field (11-2) on (111) and the maximum periphery circle of the center of a stereographic projection view, and other one magneto optics crystal is received. The Faraday-rotation child who impressed the magnetic field on the line which connected the field (-1-12) on (111) and the maximum periphery circle of the center of a stereographic projection view, and made small the amount of temperature changes of a Faraday-rotation angle.

[Claim 9] The Faraday-rotation child according to claim 1 to 8 who impressed the external magnetic field from the two directions of a parallel direction and a perpendicular direction with the permanent magnet and the electromagnet to the direction of a beam of light, and leaned the magnetization direction of a Faraday cell to the direction of a beam of light by those synthetic magnetic fields.

[Claim 10] The temperature dependence control method of the Faraday-rotation child who controls the temperature dependence of a Faraday-rotation angle by carrying out adjustable [of the magnetic field of an electromagnet] using a Faraday-rotation child according to claim 9.

[Claim 11] The optical isolator using the Faraday-rotation child according to claim 1 to 9.

[Claim 12] The optical isolator which has arranged the polarizer and the analyzer before and behind this Faraday-rotation child's direction of a beam of light, and set the magnetic field of an electromagnet as the value from which the temperature dependence of a Faraday-rotation angle becomes the minimum using the Faraday-rotation child according to claim 9.

[Claim 13] The optical attenuator using the Faraday-rotation child according to claim 1 to 9.

[Claim 14] The optical attenuator which controls the amount of transmitted lights by arranging a polarizer and an analyzer before and behind this Faraday-rotation child's direction of a beam of light, and carrying out adjustable [of the external magnetic field] with an electromagnet using a Faraday-rotation child according to claim 9.

[Translation done.]

* NOTICES *

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1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[The technical field to which invention belongs] When this invention is described in more detail about a Faraday cell and the Faraday-rotation child who has arranged the external-magnetic-field impression means so that the magnetization direction of a Faraday cell may become slanting to the direction of a beam of light, it relates to the Faraday-rotation child who reduced the amount of temperature changes of a Faraday-rotation angle using the temperature dependence of the angle alpha of the magnetization direction of a Faraday cell, and the direction of a beam of light to make. This Faraday-rotation child is useful to various kinds of optical devices using the Faraday effect, such as an optical attenuator and an optical isolator.
[0002]
[Description of the Prior Art] In the optical transmission system, the optical isolator which makes only Mukai penetrate light on the other hand, the optical attenuator for controlling the amount of transmitted lights of light, etc. are required, and the Faraday-rotation child who rotates the plane of polarization of the transmitted light is included in them. In addition, the Faraday-rotation child is used also for various kinds of optical devices, such as an optical switch, an optical circulator, a light filter, and an optical equalizer.
[0003] An optical isolator is the composition which inserted the Faraday-rotation child 3 45 degrees between the polarizers 1 and analyzers 2 which have been arranged so that it may have the plane of polarization which inclined 45 degrees mutually, as shown in drawing 21 . The Faraday-rotation child 3 is the combination of the Faraday cell which consists of a magneto optics crystal, and the permanent magnet which is an external-magnetic-field impression means, considers as the state where impressed the external magnetic field by the permanent magnet so that it might be in agreement in the direction of a beam of light, and the magneto optics crystal was saturated magnetically, and is designed by the thickness which the plane of polarization of the transmitted light rotates 45 degrees in the state. When it lets light pass to the forward direction of an optical isolator, most light which passed the polarizer 1 passes an analyzer 2 by no losing (refer to A of drawing 21). Since a polarizer 1 and plane of polarization cross at right angles by passing the Faraday-rotation child 3, the light in which the analyzer 2 was passed to it in the case of the opposite direction cannot pass a polarizer 1 (refer to B of drawing 21). Although this optical isolator is a polarization dependence type, there is also polarization a non-depended type (Japanese Patent Application No. No. 148290 [56 to]).
[0004] An example of the conventional optical attenuator is shown in drawing 2 . As shown in A of drawing 2 , it is the composition which has arranged the polarizer 14 which consists of wedge birefringence crystals (for example, rutile etc.) between the input fibers 12 and the output fibers 13 which have collimate lenses 10 and 11, respectively, the Faraday-rotation child 15, and the analyzer 16 which consists of a wedge birefringence crystal on an optical axis in this sequence (refer to Japanese Patent Application No. No. 205044 [four to]). The Faraday-rotation child 15 becomes Faraday cell (magneto optics crystal) 17 and it from the combination of the permanent magnet 18 and electromagnet 19 which impress a magnetic field from a 2-way different 90 degrees here, as shown in B of drawing 2 . The magnetization direction of Faraday cell 17 turns to the direction of the synthetic magnetic field of the fixed magnetic field by the permanent magnet 18, and the adjustable magnetic field depended electromagnet 19, and a Faraday-rotation angle changes according to it.
[0005] For example, when the polarizer 14 and the analyzer 16 have been arranged so that the optical axis of both [these] the birefringences crystal may become parallel mutually, it operates as follows. A polarizer 14 separates into Tsunemitsu o and the unusual light e the light which carried out outgoing radiation from the input fiber 12, and became a collimated beam with the 1st lens 10. The polarization direction of Tsunemitsu o and the unusual light e lies at right angles mutually. And in case the Faraday-rotation child 15 is passed, the polarization direction rotates according to the

size of magnetization parallel to an optical axis, and each light is Tsunemitsu o1 by the analyzer 16, respectively. The unusual light e1 and Tsunemitsu o2 Unusual light e2 It dissociates. Tsunemitsu o1 who does outgoing radiation from an analyzer 16 the unusual light e2 -- mutual -- parallel -- the 2nd lens 11 -- the output fiber 13 -- joining together (a solid line showing) -- unusual light e1 which carries out outgoing radiation from an analyzer 16 Tsunemitsu o2 Since it spreads, even if it is not mutually parallel, and it passes along the 2nd lens 11, it does not combine with the output fiber 13 (a dashed line shows).

[0006] Tsunemitsu o who a Faraday-rotation angle is 90 degrees (magnetization is parallel to an optical axis), and did outgoing radiation from the polarizer 14 when the impression magnetic field by the electromagnet 19 was 0 -- an analyzer 16 to unusual light e1 ****** -- the unusual light e which carried out outgoing radiation and which carried out outgoing radiation from the polarizer 14 -- an analyzer 16 to Tsunemitsu o2 ****** -- in order to carry out outgoing radiation, even if it passes along the 2nd lens 11, it does not combine with the output fiber 13 Tsunemitsu o who the Faraday-rotation angle approached 0 times and did outgoing radiation from the polarizer 14 to it when the impression magnetic field by the electromagnet 19 was large enough -- almost -- as it is -- an analyzer 16 to Tsunemitsu o1 ****** -- the unusual light e which carried out outgoing radiation and which carried out outgoing radiation from the polarizer 14 is unusual from an analyzer 16 almost as it is -- optical e<SUB>2 In order to carry out outgoing radiation, both light is parallel and is altogether combined with the output fiber 13 with the 2nd lens 11. Thus, according to the impression magnetic field strength by the electromagnet 19, magnetization rotates, it will change in the range from about 90 degrees to about 0 times, the quantity of lights combined with the output fiber 13 according to it will differ, and a Faraday-rotation angle will function as an optical attenuator.

[0007] In addition, when it has arranged so that the optical axis of both the birefringences crystal of a polarizer 14 and an analyzer 16 may intersect perpendicularly mutually, when a Faraday-rotation angle is 90 degrees, the amount of transmitted lights becomes the above and reversely with the maximum, and, in the case of 0 times, the amount of transmitted lights becomes with the minimum.

[0008] In addition, as a Faraday cell included in these Faraday-rotation child, Bi (bismuth) substitution rare-earth-iron-garnet single crystal film (LPE film) mainly produced by the LPE method (liquid-phase-epitaxial method) is used in recent years. The reason is that, as for a LPE film, a Faraday-rotation coefficient has a large advantage compared with a YIG (yttrium iron garnet) single crystal by contribution of Bi.

[0009]

[Problem(s) to be Solved by the Invention] However, this Bi substitution rare-earth-iron-garnet single crystal film has the fault that the temperature dependence of a Faraday-rotation angle is large. Therefore, a Faraday-rotation child's temperature dependence also becomes large, and the problem that the temperature characteristic of devices, such as an optical isolator produced using this Faraday-rotation child and an optical attenuator, is large produces it.

[0010] in order [then,] to improve this temperature characteristic -- ** -- the method (Japanese Patent Application No. No. 243217 [60 to]) of improving the physical properties of a crystal by making it a special composition system

** How (Japanese Patent Application No. No. 134372 [60 to], Japanese Patent Application No. No. 180757 [two to]) to improve a Faraday-rotation child's temperature dependence by using two garnet crystals for a magneto-optics element, and making the temperature dependence of a Faraday-rotation angle offset

** Technology of considering a polarizer and an analyzer as the optimal arrangement and improving the temperature characteristic as a device (Japanese Patent Application No. No. 45231 [eight to])

It ******.

[0011] However, there are the respectively following problems in such a proposal. ** The method makes temperature dependence of a Faraday-rotation angle small by adding Tb to Bi substitution rare earth iron garnet which is a magneto-optics element. However, when an optical isolator is constituted considering the publication of an example, the thickness of the magneto-optics element in the wavelength of 1.5 micrometers when temperature dependence is the smallest is set to about 1700 micrometers, and quality crystal training by the LPE method is very thick, considering the thickness of about 500 micrometers being a limitation. ** By the method, in order to have to produce two different crystals, cost increases. The point (amount) that plane of polarization and an analyzer are in a rectangular state decreasing [maximum light] technology ** The angle of plane of polarization, To in other words being sensitive to a Faraday-rotation angle from the maximum light-transmission point (amount) that plane of polarization and an analyzer are in an parallel state being insensible on a Faraday-rotation square When the Faraday-rotation angle to which the absolute value of the amount of temperature changes of a Faraday-rotation angle becomes the largest is the maximum, When the Faraday-rotation angle to which plane of polarization and an analyzer become parallel, and the absolute value of the amount of temperature changes of a Faraday-rotation angle becomes the smallest is the minimum, As plane of polarization and the analyzer changed into the rectangular state, the maximum light magnitude of attenuation and the optical attenuator which made small temperature dependence of an insertion loss (the amount of the maximum

light transmissions) are realized. However, although the point decreasing [maximum light] must make very small temperature dependence of the Faraday-rotation angle in eye a sensitive hatchet and its point at a Faraday-rotation angle, since a Faraday-rotation child essentially has temperature dependence, there is a limitation in temperature dependence reduction.

[0012] The purpose of this invention is offering the technology of reducing the temperature dependence of a Faraday-rotation angle based on a new principle. Other purposes of this invention are offering a Faraday-rotation child with the small temperature dependence of a Faraday-rotation angle. The purpose of further others of this invention is offering the optical device which used Faraday-rotation children, such as a good optical attenuator of the temperature characteristic.

[0013]

[Means for Solving the Problem] this invention is a Faraday-rotation child who rotates the plane of polarization of the polarization which penetrates a Faraday cell by impressing an external magnetic field to a Faraday cell. The variation of the Faraday-rotation angle by the temperature dependence of an angle alpha and the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect impress an external magnetic field in the direction in which it is a different sign mutually, and one absolute value becomes under the double precision of the absolute value of another side, and when the angle of the magnetization direction of a Faraday cell and the direction of a beam of light to make is set to alpha, it constitutes from this invention so that the amount of temperature changes of a Faraday-rotation angle may be made small. Of course, the composition which offsets mostly the variation of the Faraday-rotation angle by the temperature dependence of an angle alpha and the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect by impressing an external magnetic field in the direction in which it is a different sign mutually, and an absolute value becomes almost equal is best.

[0014] A Faraday cell consists of a single or multiple magneto optics crystal. When a Faraday cell consists of two or more magneto optics crystals, there is composition which arranges and arranges those directions and impresses an external magnetic field. That is, when the angle of the magnetization direction of each magneto optics crystal and the direction of a beam of light to make is set to alpha, the variation of the Faraday-rotation angle by the temperature dependence of an angle alpha and the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect impress an external magnetic field to the single direction in which it is a different sign mutually, and one absolute value becomes under the double precision of the absolute value of another side, and make small the amount of temperature changes of a Faraday-rotation angle.

[0015] Moreover, when a Faraday cell consists of two or more magneto optics crystals, there is also composition which changes and arranges those directions and impresses an external magnetic field. The variation of an angle alpha 1, alpha 2, and the Faraday-rotation angle by the temperature dependence of ... when the angle of the magnetization direction of each magneto optics crystal and the beam-of-light transparency direction to make is made into alpha 1, alpha 2, and ..., Total with the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect impresses an external magnetic field in the direction which becomes in an absolute value below total of the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect of each magneto optics crystal, and makes small the amount of temperature changes of a Faraday-rotation angle.

[0016]

[Embodiments of the Invention] As a magneto optics crystal used as a Faraday cell, there is 3 (RBi) 5 (FeM) O12 or (RBi) 3 Fe 5O12 (however, one or more sorts of elements chosen from the rare earth elements in which R contains an yttrium, one or more sorts of elements which M can replace by iron) produced, for example by the liquid-phase-epitaxial method. Typically, it is the becoming composition Tb1.00Y0.65Bi1.35Fe4.05Ga0.95O12. Moreover, the garnet single crystal of the becoming composition is sufficient Y3 Fe5 O12.

[0017] In the Faraday-rotation child of this invention, an external magnetic field is impressed so that the magnetization direction of a Faraday cell may be leaned from a beam of light. For example, the permanent magnet of a couple or an electromagnet is aslant arranged to the direction of a beam of light. Or there is also composition which impresses a magnetic field from the 2-way of a parallel direction and a perpendicular direction to the direction of a beam of light. For example, in another side, by the permanent magnet, one side impresses a magnetic field with an electromagnet.

[0018] The above Faraday-rotation children can use for various kinds of optical devices, such as an optical isolator, an optical attenuator, an optical switch, an optical circulator, a light filter, and an optical equalizer.

[0019]

Background of the Invention] If magnetization of a Faraday cell considers as angle alpha ********** from a beam of light in case light passes Faraday cell 20 as shown in A of drawing 1 , it is Faraday-rotation angle thetaF. It can express with the following ** formula so that B of drawing 1 may show.

thetaF =theta Fmaxxcos alpha -- **thetaFmax is the maximum of a Faraday-rotation angle and is the case where the

magnetization direction is in agreement in the direction of a beam of light. Plane of polarization rotates only the direction component of a beam of light of magnetization. I hear that the magnetization direction of a Faraday cell is influenced by the crystal magnetic anisotropy of a magneto optics crystal besides the impression magnetic field from the outside, and an important thing has it here. That is, not only thetaFmax but the angle alpha is the function of temperature T. Then, the above-mentioned ** formula can be expressed like the following ** formula.
thetaF (T) =thetaFmax(T) xcos alpha (T) -- The temperature coefficient of a Faraday-rotation angle is dthetaF from **** formula. /dT=cos alphaxdthetaFmax/dT+theta Fmaxx(-sin alpha) xd alpha/dT -- It becomes **. It is a constant term here C1 =cos alphaC2 =thetaFmaxx (-sin alpha)
When it carries out, the above-mentioned ** formula can be expressed as follows.
dthetaF /dT=C1 x dthetaFmax/dT+C 2 xd alpha/dT -- ** -- this 1st term of the right-hand side is the temperature coefficient of the Faraday-rotation angle by the temperature dependence of the Faraday effect of a Faraday cell to it, the 2nd term of the right-hand side boils the rate of change of the Faraday-rotation angle by the temperature dependence of the angle alpha of the magnetization direction of a Faraday cell, and the direction of a beam of light to make, and corresponds, and the temperature change of this angle alpha makes the origin temperature dependence of the crystal magnetic anisotropy of the magneto optics crystal which is mainly a Faraday cell In the case of the Faraday-rotation child who is incidentally using it by the conventional optical isolator, since the sufficiently big external magnetic field is impressed in the direction of a beam of light and the magnetization direction of a Faraday cell is always in agreement in the direction of a beam of light, the 2nd term of the right-hand side of the aforementioned ** is always zero, and only the temperature coefficient of material becomes with a problem.
[0020] As mentioned above, although a numeric value cannot be moved in design since the 1st term of the right-hand side is decided by physical properties, since, as for the 2nd term, the angle alpha is contained, also greatly and small depending on the direction of a crystal, the numeric value is made also including a sign. That is, if magnetization is turned to the specific direction of a Faraday cell, the sign of the 1st term of the right-hand side and the 2nd term is made reversely, the variation of a Faraday-rotation angle will be mostly offset by it, and things will enable it to make temperature dependence of a Faraday-rotation angle small.
[0021] The system of measurement shown in drawing 3 was produced, the external-magnetic-field impression direction to a Faraday cell, and the drive current value and temperature of an electromagnet were changed arbitrarily, and the Faraday-rotation angle was measured by the rectangular polarizer method. This is the same composition as an optical attenuator fundamentally. The light which carried out outgoing radiation from the optical fiber 30 turns into parallel light with a lens 31, passes a polarizer 32, Faraday cell 33, and an analyzer 34, and condenses at the incidence edge of an optical fiber 36 with a lens 35. The portion of a sign 38 is a Faraday-rotation child here, and the example is shown in drawing 4 . Those synthetic magnetic fields are changed by the magnetic field which saturation takes to an optical axis in parallel with the permanent magnets 40 and 41 of a couple being impressed to Faraday cell 33, and a magnetic field being impressed to an optical axis and a perpendicular direction with an electromagnet 42, and changing the coil current of this electromagnet 42. The garnet single crystal was used for the Faraday cell.
[0022] The garnet single crystal which serves as a Faraday cell first was produced as follows. PbO-B2 O3-Bi 2O3 It considered as the fusing agent and Bi substitution rare-earth-iron-garnet single crystal (a LPE film, composition Tb1.00Y0.65Bi1.35Fe4.05Ga 0.95O12, 450 micrometers of thickness) was raised by the liquid-phase-epitaxial method (the LPE method) on the field (111) of the substrate which is the diameter of 3 inches and thickness of 1170 micrometers whose composition a lattice constant is 12.496A and is 3 (CaGd) 5 (MgZrGa) O12. As shown in drawing 5 , the flat side (orientation flat) of two size is beforehand attached to the substrate 50, a big flat side is a field (-110), and a small flat side is a field (11-2). A sign 52 shows a LPE film. Next, after it cut the obtained LPE film to 7.6mmx5.0mm and polish removed the substrate, 1100 degrees C was heat-treated in the atmosphere for 8 hours. This is for reducing the uniaxial-magnetic-anisotropy constant by growth guidance. Then, it ground again, the mirror finish was carried out to the 7.6mmx5.0mmx0.33mm configuration, and the antireflection film was deposited to the field (111) of front reverse side both sides. And it cut to 1.0mmx1.2mmx0.33mm, finally some intersections of a field (111), a field (-110), and a field (-1-12) were deleted, and it considered as the mark of a direction. The configuration and field of a final garnet single crystal are shown in D of drawing 5 . Since it was 120 oersted when the magnetization which the saturation of a garnet single crystal takes with an oscillating sample type magnetometer (VSM) was measured, the fixed field system by the permanent magnet is set as 150 oersteds, and it was made to saturate a garnet single crystal. And light measured by [as carrying out incidence perpendicularly to the field which deposited the antireflection film of a garnet single crystal, i.e., (111) a field,]. A Faraday-rotation angle when magnetization of this garnet single crystal turns to a beam of light and a parallel direction is about 32 degrees. (Although a bar is lengthened and expressed in addition with the notation showing the field and direction of a crystal on the numeric value about a negative index, since it is not made, on these specifications, the minus sign has been attached and written to the index.)

[0023] Drawing 6 is a stereographic projection view centering on the field (111) of a garnet single crystal. An adjacent concentric circle means a mutually different field by a unit of 10 degrees, and the line of the adjacent direction of a path means a mutually different field by a unit of 10 degrees. Therefore, the arbitrary fields of a garnet single crystal can be shown as a point in this stereographic projection view.
[0024] The magnetic field of 150 oersteds was impressed to the garnet single crystal in the direction of a side front from the background of the space perpendicular direction of drawing 6 with the permanent magnet, and it is saturated by it. The direction of 24 degrees and c direction <-101> were impressed to the place of this state, the magnetic field was impressed to d direction <-211> with the electromagnet from b direction <-1-12> direction to a direction <-1-12> and the <-101> direction, and the Faraday-rotation angle was measured. Measurement was performed by three points whose temperature is 10 degrees C, 25 degrees C, and 65 degrees C.
[0025] The measurement result of a Faraday-rotation angle is shown in drawing 7 - drawing 10 . When drawing 7 - drawing 10 are compared, it turns out that the spectrum of a Faraday-rotation angle changes greatly with directions of an impression magnetic field. This is because the Faraday-rotation angle observed contains not only contribution but the thing which makes a crystalline anisotropy the origin although it makes the Faraday effect the origin. The garnet single crystal has the crystal magnetic anisotropy, <111> direction and its symmetrical equivalent direction are easy axes by it, and <100> direction and its symmetrical equivalent direction are hard axis. And the size of a crystal magnetic anisotropy becomes so large that it becomes low temperature (P. Thin Solid Films, such as Hansen, 114 (1984) 69-107).
[0026] Drawing 7 is the case where the magnetic field of an electromagnet is impressed to <-1-12> direction. That is, the synthetic magnetic-field-vector path of an electromagnet and a permanent magnet is set to a of drawing 6 , and there is a field (001) near the center of a path, and in accuracy (111) from a field at 55 degrees. The cross section of Path a is shown in drawing 11 . It is easy to turn [magnetization / of the garnet single crystal 60] to the <111> directions and <-1-11> direction which are an easy axis, and is hard to turn / magnetization / to the <001> directions of hard axis. The extent becomes so large that it becomes low temperature. Therefore, in order to pass through <001> directions quickly and to approach <-1-11> direction so that it becomes low temperature, the spectrum of a Faraday-rotation angle comes to be shown in drawing 7 . When a Faraday-rotation angle (10 degrees C and 25 degrees C) enlarges the magnetic field of an electromagnet, the sign is negative from positive, because the direction component of a beam of light of magnetization changed in the right direction from the opposite direction to the travelling direction of a beam of light. In drawing 7 , the temperature dependence of a Faraday-rotation angle differs greatly by three points whose current value is 15mA, 20mA, and 25mA. At a 15mA point, the temperature coefficient of a Faraday-rotation angle is negative, and it is about 0 in 20mA, and is positive in 25mA.
[0027] This phenomenon can be explained as follows. The temperature coefficient of a Faraday-rotation angle is decided by ** formula as mentioned above. ** Since, as for contribution which makes the origin the Faraday effect of the 1st term of the right-hand side of a formula, the Faraday effect becomes small in connection with a temperature rise, a Faraday-rotation angle becomes small and the temperature coefficient of the right-hand side, i.e., the 1st term, serves as negative. Since the directions of a synthetic magnetic field vector of an electromagnet and a permanent magnet differ when current value differs to it (that is, the direction of an impression magnetic field to a Faraday cell changes), contribution of the 2nd term of the right-hand side which is the temperature coefficient of the Faraday-rotation angle of the anisotropy origin differs on each point. At a 15mA point, in order that magnetization of a crystal may not bring close to <001> directions so that it becomes low temperature, the angle of rotation alpha of magnetization becomes small. Conversely, alpha becomes large, so that temperature is high, if it says, therefore the temperature coefficient of the 2nd term becomes negative. Therefore, temperature coefficient dthetaF of the Faraday-rotation angle by which a temperature coefficient is negative and both the 1st term and the 2nd term are observed /dT also becomes negative. Although magnetization of a crystal does not bring it close to <001> directions so that even a 25mA point becomes low temperature, since it has already passed, the angle of rotation alpha of magnetization becomes large. Conversely, alpha becomes small, so that temperature is high, if it says. Therefore, the temperature coefficient of the 2nd term is the temperature coefficient dthetaF of the Faraday-rotation angle which just becomes, and is observed since the size is larger than the 1st term. /dT just becomes. To these, at a 20mA point, the 2nd term is positive, and moreover, since the size is almost the same as the 1st term, a temperature coefficient is offset and is set to about 0.
[0028] Drawing 8 is the case where the magnetic field of an electromagnet is impressed in the direction of 24 degrees from <-1-12> direction to <-101> direction. That is, the path of the synthetic magnetic field vector of an electromagnet and a permanent magnet is set to b of drawing 6 . Although there is neither an easy axis nor hard axis on a path, <001> directions are located in near. The 1st term of the right-hand side and the 2nd term of ** formula are offset by this influence, and the Faraday-rotation angle has become the almost same value at 10 degrees C, 25 degrees C, and 65

degrees C.
[0029] Drawing 9 is the case where the magnetic field of an electromagnet is impressed to <-101> direction. That is, the synthetic magnetic-field-vector path of an electromagnet and a permanent magnet is c of drawing 6 , it is most separated from an easy axis or hard axis, and a nearby easy axis and nearby hard axis are symmetrically located from this path. For example, <-1-11> of a nearby easy axis, <-111> or <001> of hard axis, and <-100> are located in the place where Path c serves as a symmetry axis. Therefore, the magnetization direction of a crystal is hardly influenced of an anisotropy, but follows in the direction of a synthetic vector of the magnetic field of an electromagnet and a permanent magnet. In the temperature coefficient, most contribution of the 2nd term cannot be found and serves as negative by contribution of the 1st term.
[0030] Drawing 10 is the case where the magnetic field of an electromagnet is impressed to <-211> direction. That is, the synthetic magnetic-field-vector path of an electromagnet and a permanent magnet is set to d of drawing 6 , and a field (-111) is located from a main field (111) in the position of 70 degrees. It becomes easy to turn [magnetization] to <111> directions and <-111> direction, so that it becomes low temperature. <-111> Faraday-rotation angles when magnetization of a crystal has turned to the direction are 70= 11 Faraday-rotation angle xcos 70=32 degree xcos(es) when magnetization has turned to the direction of a beam of light. The spectrum of drawing 10 of the thing with the large Faraday-rotation angle in a side with large current value is because magnetization of a crystal is suitable near the <-111> direction compared with the spectrum of drawing 9 .
[0031] Thus, by impressing a magnetic field in the specific direction of a garnet single crystal, the sign of the 1st term and the 2nd term is made reversely, by it, the variation of a Faraday-rotation angle can offset each other, and temperature dependence of a Faraday-rotation angle can be made small. Moreover, since a magnetic field may be impressed in the existing single specific direction like drawing 7 and drawing 8 as the means and the spectrums of drawing 7 - drawing 10 differ greatly, a magnetic field is impressed to a Faraday cell in the arbitrary directions of each crystal using two or more garnet single crystals, and you may make it the temperature dependence of the Faraday-rotation angle of those total become small.
[0032] In addition, when the magnetic field of an electromagnet was impressed to <-1-12> direction of Path a in drawing 6 from the symmetric property of a crystal, and when a magnetic field is impressed to the equivalent direction, symmetry <-12-1> which is got blocked and located in 120 degrees from <-1-12> direction direction, and <2-1-1> direction, behavior of a Faraday-rotation angle becomes the same. Similarly, also in path b-d, the same result is brought in the symmetrical equivalent direction.
[0033]
[Example] (Example 1) The system of measurement shown in drawing 3 was produced, and the temperature characteristic of a Faraday-rotation angle was first measured by the rectangular polarizer method. Next, it fixed so that the angle at which the plane of polarization of the light which passes them makes a polarizer and an analyzer might turn into 135 degrees, and the temperature characteristic of the optical magnitude of attenuation was measured. The magnetic fields of a permanent magnet are 150 oersteds, and the drive current value of an electromagnet was fixed by 20mA. This system of measurement is fundamentally the same as an optical isolator, and the optical magnitude of attenuation is equivalent to an opposite direction insertion loss.
[0034] The garnet single crystal used as a Faraday cell was produced in the procedure as shown in drawing 5 . PbO-B2 O3-Bi 2O3 It considered as the fusing agent and Bi substitution rare-earth-iron-garnet single crystal (a LPE film, composition Tb1.00Y0.65Bi1.35Fe4.05Ga 0.95O12, 450 micrometers of thickness) was raised by the LPE method on the field (111) of the substrate which is the diameter of 3 inches and thickness of 1170 micrometers whose composition a lattice constant is 12.496A and is 3 (CaGd) 5 (MgZrGa) O12. As shown in drawing 5 , the flat side of two size is beforehand attached to the substrate, a big flat side is a field (-110), and a small flat side is a field (11-2). Next, after it cut the obtained LPE film to 7.6mmx5.0mm and polish removed the substrate, 1100 degrees C was heat-treated in the atmosphere for 8 hours. This is for reducing the uniaxial-magnetic-anisotropy constant by growth guidance. Then, it ground again, the mirror finish was carried out to the 7.6mmx5.0mmx0.35mm configuration, and the antireflection film was deposited to the field (111) of front reverse side both sides. And it cut to 1.0mmx1.2mmx0.35mm, finally some intersections of a field (111), a field (-110), and a field (-1-12) were deleted, and it considered as the mark of a direction. Since it was 120 oersted when the magnetization which the saturation of a garnet single crystal takes with an oscillating sample type magnetometer (VSM) was measured, the fixed field system by the permanent magnet is made into 150 oersteds, and it was made to saturate a garnet single crystal. And light measured by [as carrying out incidence perpendicularly to the field which deposited the antireflection film of a garnet single crystal, i.e., (111) a field,].
[0035] As shown in A of drawing 12 , Faraday cell 70 arranged three pieces and the direction, put the above magnetic garnet single crystals 72 in order, and has arranged the field (-1-12) of the side which beveled the angle to the south pole side of an electromagnet. That is, the magnetic field of an electromagnet is impressed to <-1-12> direction. In the

case of the current value of 20mA of the electromagnet in the path a of drawing 7 , this corresponds. A garnet single crystal has the Faraday-rotation angle of about 34 degrees, when magnetization turns to a beam of light and a parallel direction, and it has a 34 degree x3 piece =102 degree Faraday-rotation angle as a Faraday cell. Since the thickness of the raised crystal is 450 micrometers and it is processed and used, thickness becomes thin and three garnet single crystals are used here, because the Faraday-rotation angle per piece is small. At present, a defect and a crack arise and crystal training by the LPE method is difficult to raise, if thickness exceeds 500 micrometers. However, if training of the thick film which training technology will progress in the future and exceeds 500 micrometers is attained, enlarges thickness per crystal after processing and can enlarge a Faraday-rotation angle, two pieces or one piece will be available for the number of the garnet single crystal to be used.

[0036] A magnetic field perpendicular to the direction of a beam of light is impressed to a garnet single crystal with an electromagnet, and a magnetic field parallel to the direction of a beam of light is impressed with a permanent magnet. The measurement result of a Faraday-rotation angle is shown in drawing 13 , and the measurement result of the optical magnitude of attenuation is shown in drawing 14 . When the temperature dependence of a Faraday-rotation angle and the optical magnitude of attenuation of an example 1 is small and it is used as an optical isolator from these drawings, it turns out that it is effective. In actually producing an optical isolator, may lean magnetization of a magnetic garnet single crystal from an optical axis using a permanent magnet and an electromagnet like this example, and May arrange the permanent magnet of a couple aslant to an optical axis, may lean magnetization of a magnetic garnet single crystal from an optical axis, and The permanent magnet of the shape of one cylinder may be aslant placed to an optical axis, into it, a magnetic garnet single crystal may be placed so that the field which is a vacuum evaporationo side (111) may become an optical axis and a perpendicular, and you may lean magnetization of a magnetic garnet single crystal from an optical axis. In any case, an effect is the same, and the temperature dependence of a Faraday-rotation angle becomes small.

[0037] It sets to drawing 13 and drawing 14 , and Comparison A is produced and measured in the following procedure. A Faraday cell uses what was used in the example 1, and two things which made the same magnetic garnet single crystal the thickness of 0.233mm, and when the magnetization direction turns to the direction of a beam of light, and a parallel direction, it has the Faraday-rotation angle of about 45 degrees. From the system of measurement of drawing 3 , except for the electromagnet, a Faraday-rotation angle and the optical magnitude of attenuation impressed only the magnetic field of a permanent magnet to the crystal, and measured it. Moreover, both of magnetic garnet single crystals are arranged so that a beam of light may carry out incidence perpendicularly to the field which deposited the antireflection film of a garnet single crystal, i.e., (111), a field. With the permanent magnet, magnetization of a magnetic garnet single crystal is saturated and the direction has become an optical axis and parallel. The temperature characteristic of a Faraday-rotation angle was first measured by the rectangular polarizer method. Next, it fixed so that the angle at which the plane of polarization of the light which passes them makes a polarizer and an analyzer might turn into 135 degrees, and the temperature characteristic of the optical magnitude of attenuation was measured. This system of measurement is fundamentally the same as the conventional optical isolator, and the optical magnitude of attenuation is equivalent to an opposite direction insertion loss.

[0038] (Example 2) The garnet single crystal was produced in the same procedure as (an example 1). However, a size is 1.0mmx1.2mmx0.33mm, and when magnetization turns to the direction of a beam of light, and a parallel direction, it has the Faraday-rotation angle of about 32 degrees. The system of measurement of drawing 3 was used and the temperature dependence of a Faraday-rotation angle was first measured by the rectangular polarizer method. Next, the polarizer and the analyzer were installed so that the angle which the plane of polarization of the passing light makes might turn into 105 degrees, and the temperature characteristic of the optical magnitude of attenuation was measured. The magnetic fields of a permanent magnet are 150 oersteds, and it carried out adjustable [of the drive current value of an electromagnet] by 0-80mA. This system of measurement is fundamentally the same as an optical attenuator. As shown in B of drawing 12 , Faraday cell 74 changed the magnetic garnet single crystal 72 produced above, put three pieces and the direction in order, made (-1-12) of the side to which two back garnet single crystals beveled the field (-1-12) of the side which the garnet single crystal of most this side beveled to the south pole side of an electromagnet the N very side, and has arranged it. [electromagnet] A magnetic field perpendicular to the direction of a beam of light is impressed to a garnet single crystal with an electromagnet, and a magnetic field parallel to the direction of a beam of light is impressed with a permanent magnet. This receives two back garnet single crystals. It means impressing a magnetic field on the line which connected the field (11-2) on (111) and the maximum periphery circle of the center of a stereographic projection view, and impressing a magnetic field to one magneto optics crystal of most this side on the line which connected the field (-1-12) on (111) and the maximum periphery circle of the center of a stereographic projection view.

[0039] The measurement result of a Faraday-rotation angle is shown in drawing 15 , and the measurement result of the

optical magnitude of attenuation is shown in drawing 16 . It turns out that the temperature dependence of the Faraday-rotation angle in the place where the current value of an electromagnet is large is smaller than drawing 15 . Moreover, as for drawing 16 , that it is also small shows the temperature dependence of the optical magnitude of attenuation. These results to this composition is effective in a magneto-optics formula adjustable light attenuator.

[0040] (Example 3) The garnet single crystal was produced in the same procedure as (an example 1). However, a size is 1.0mmx1.2mmx0.33mm, and when magnetization turns to the direction of a beam of light, and a parallel direction, it has the Faraday-rotation angle of about 32 degrees. The system of measurement of drawing 3 was used and the temperature dependence of a Faraday-rotation angle was first measured by the rectangular polarizer method. Next, the polarizer and the analyzer were installed so that the angle which the plane of polarization of the passing light makes might turn into 105 degrees, and the temperature characteristic of the optical magnitude of attenuation was measured. The magnetic fields of a permanent magnet are 150 oersteds, and it carried out adjustable [of the drive current value of an electromagnet] by 0-80mA. This system of measurement is fundamentally the same as an optical attenuator. Like A of drawing 12 , Faraday cell 70 arranged three pieces and the direction, put in order the magnetic garnet single crystal 72 produced above, and impressed the magnetic field of an electromagnet in the direction of 24 degrees from <-1-12> direction to the <-101> direction. A magnetic field perpendicular to the direction of a beam of light is impressed to a garnet single crystal with an electromagnet, and a magnetic field parallel to the direction of a beam of light is impressed with a permanent magnet. This means impressing a magnetic field to a magneto optics crystal on the line which connected the position of 24 degrees to the field from the field (-1-12) on (111) and the maximum periphery circle of the center of a stereographic projection view (-101).

[0041] The measurement result of a Faraday-rotation angle is shown in drawing 17 , and the measurement result of the optical magnitude of attenuation is shown in drawing 18 . Drawing 17 shows that the temperature dependence of a Faraday-rotation angle is small. Moreover, as for drawing 18 , that it is also small shows the temperature dependence of the optical magnitude of attenuation. These results to this composition is effective in a magneto-optics formula adjustable light attenuator.

[0042] (Example 1 of reference) The garnet single crystal was produced in the same procedure as (an example 1). However, a size is 1.0mmx1.2mmx0.33mm, and when magnetization turns to the direction of a beam of light, and a parallel direction, it has the Faraday-rotation angle of about 32 degrees. The system of measurement of drawing 3 was used and the temperature dependence of a Faraday-rotation angle was first measured by the rectangular polarizer method. Next, the polarizer and the analyzer were installed so that the angle which the plane of polarization of the passing light makes might turn into 105 degrees, and the temperature characteristic of the optical magnitude of attenuation was measured. The magnetic fields of a permanent magnet are 150 oersteds, and it carried out adjustable [of the drive current value of an electromagnet] by 0-80mA. This system of measurement is fundamentally the same as an optical attenuator. Like A of three pieces and drawing 12 , the Faraday cell arranged the direction, put in order the garnet single crystal produced above, made the field (-110) the south pole side of an electromagnet, and has arranged it. That is, the magnetic field of an electromagnet is impressed to <-110> direction. A magnetic field perpendicular to the direction of a beam of light is impressed to a garnet single crystal with an electromagnet, and a magnetic field parallel to the direction of a beam of light is impressed with a permanent magnet.

[0043] The measurement result of a Faraday-rotation angle is shown in drawing 19 , and the measurement result of the optical magnitude of attenuation is shown in drawing 20 . Drawing 19 and drawing 20 show that the temperature dependence of a Faraday-rotation angle and the optical magnitude of attenuation is large. These results to this composition is unsuitable as a magneto-optics formula adjustable light attenuator.

[0044]

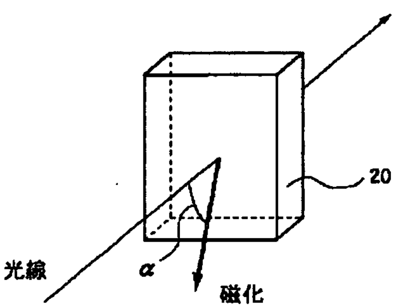
[Effect of the Invention] Can constitute this invention so that the variation of the Faraday-rotation angle by the temperature dependence of the angle of the magnetization direction of a magneto optics crystal and the direction of a beam of light make, and the variation of the Faraday-rotation angle by the temperature dependence of the Faraday effect may be offset as much as possible, and the effect that the amount of a Faraday-rotation angle of temperature changes can reduce also in the use form from which the magnetization direction changes as the result produces it by using the temperature dependence of the crystal magnetic anisotropy of a magneto optics crystal it is temperature-independent to a Faraday cell as mentioned above.

[Translation done.]

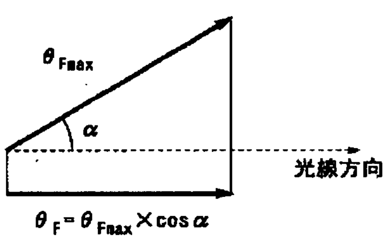
DRAWINGS

[Drawing 1]

A

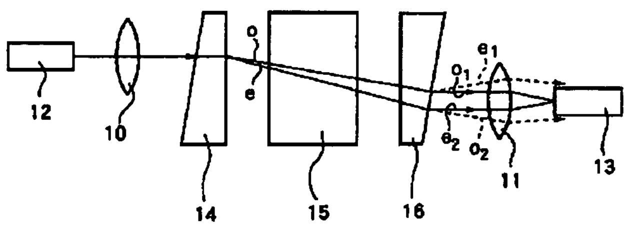


B



[Drawing 2]

A



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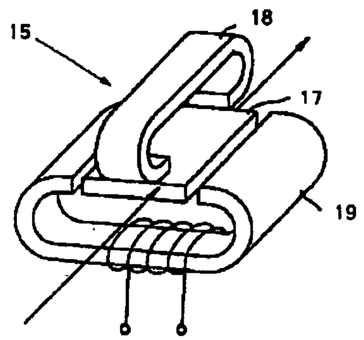
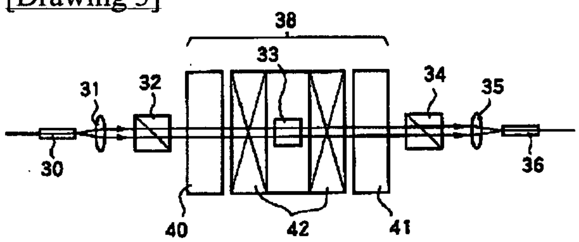
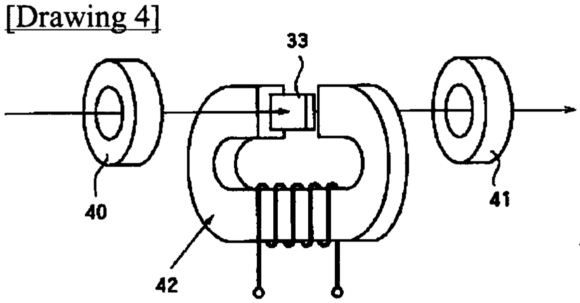


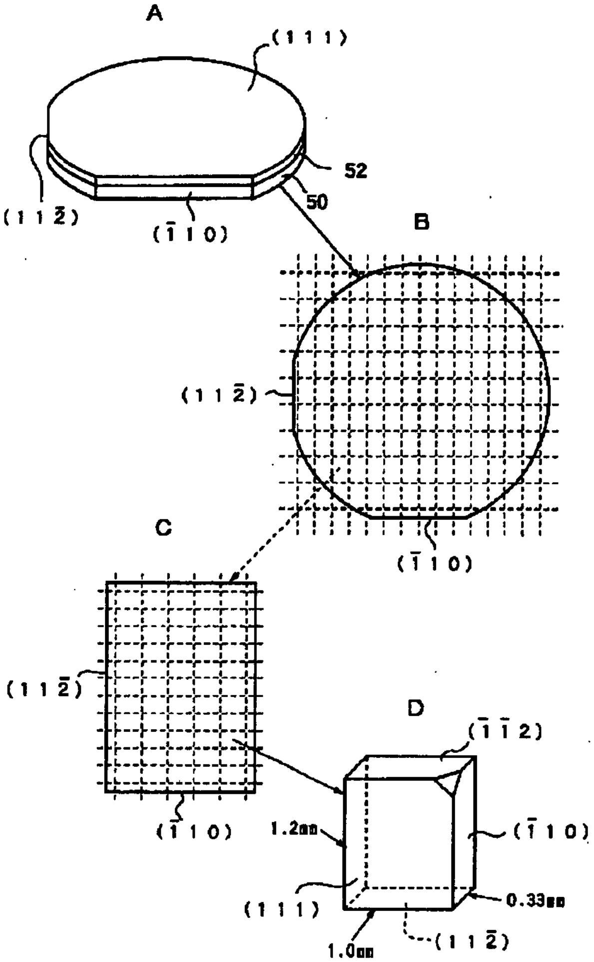
[Drawing 3]



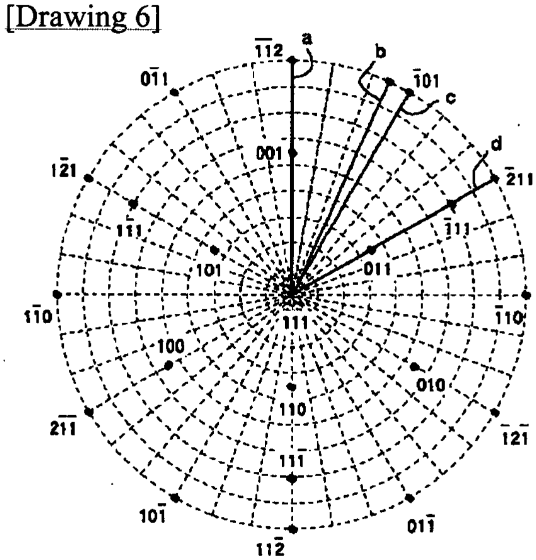
[Drawing 4]



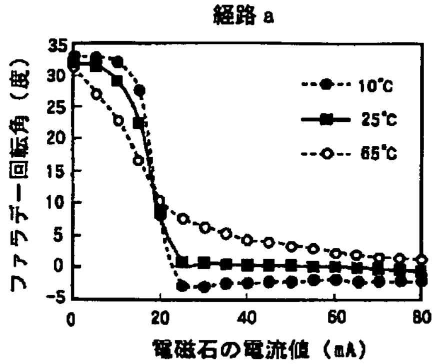
[Drawing 5]



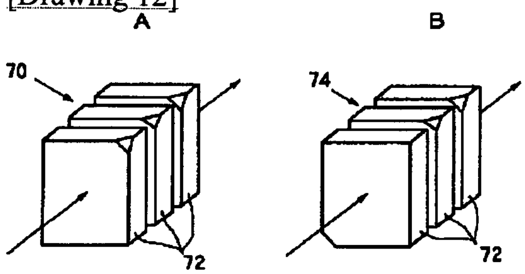
[Drawing 6]



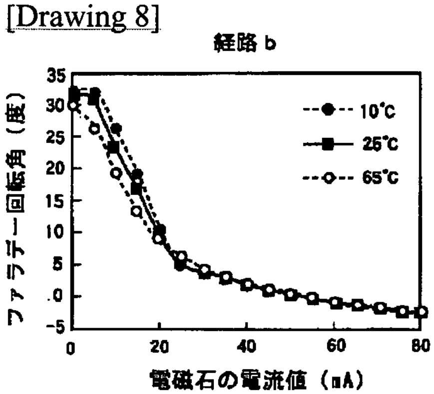
[Drawing 7]



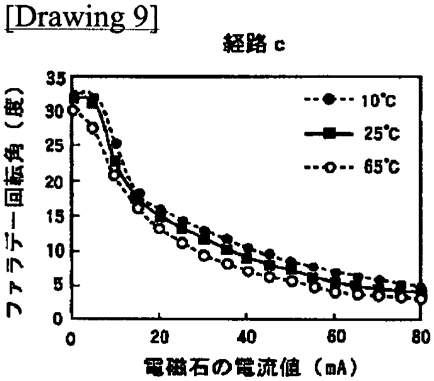
[Drawing 12]



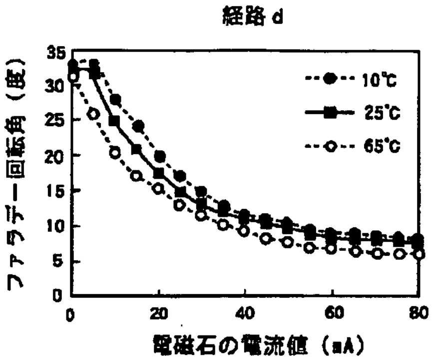
[Drawing 8]



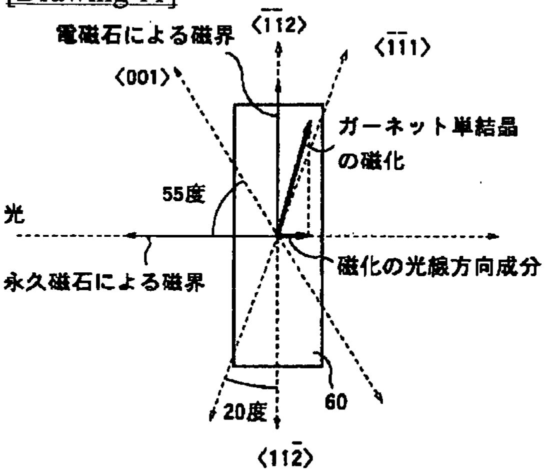
[Drawing 9]



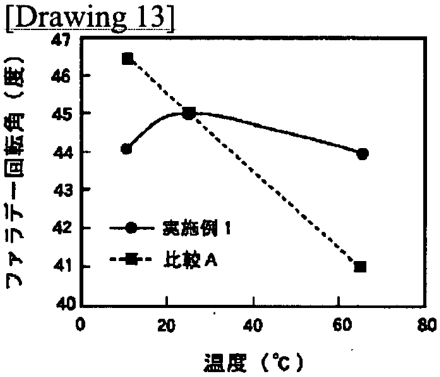
[Drawing 10]



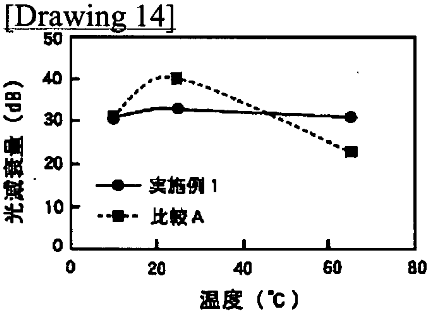
[Drawing 11]



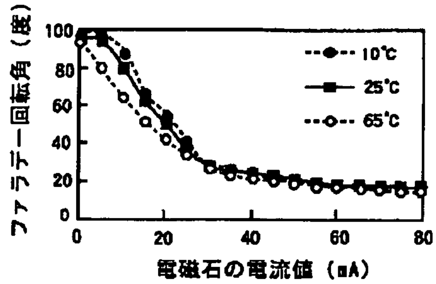
[Drawing 13]



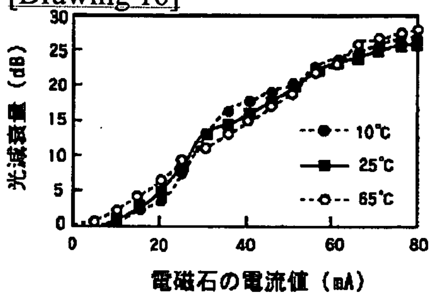
[Drawing 14]



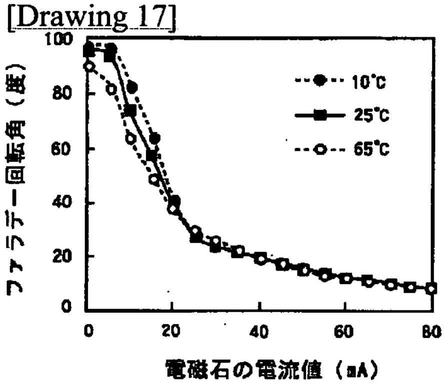
[Drawing 15]



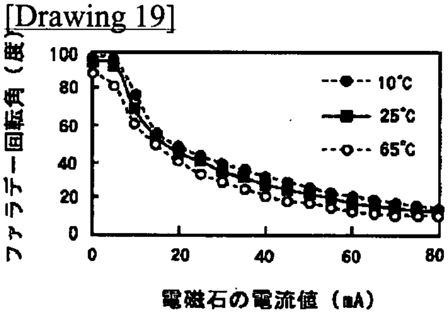
[Drawing 16]



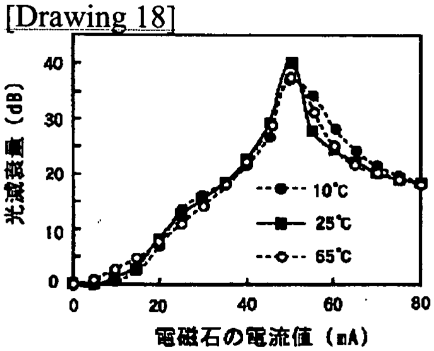
[Drawing 17]



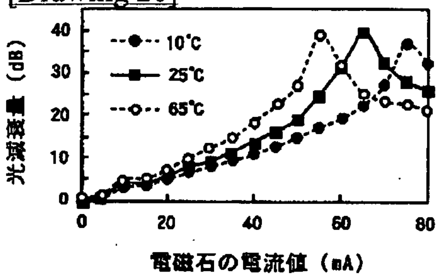
[Drawing 19]



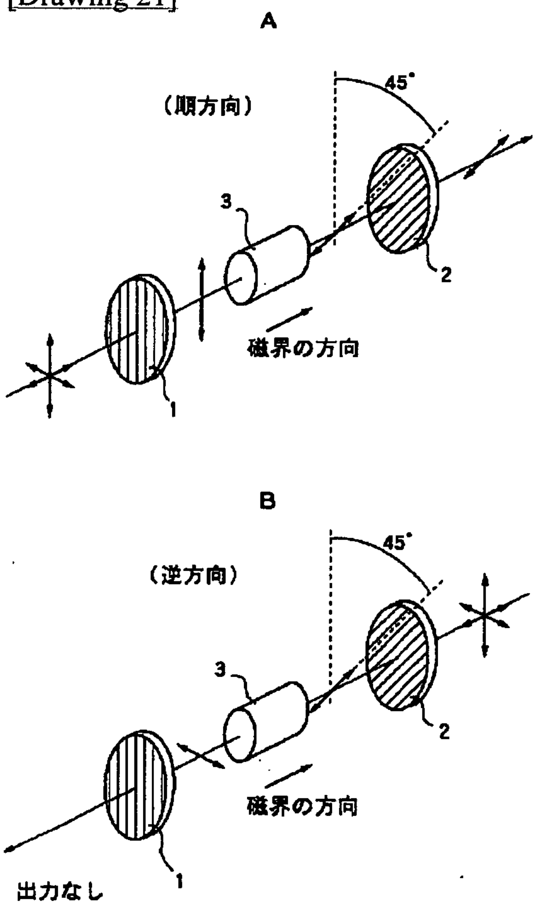
[Drawing 18]



[Drawing 20]



[Drawing 21]



[Translation done.]